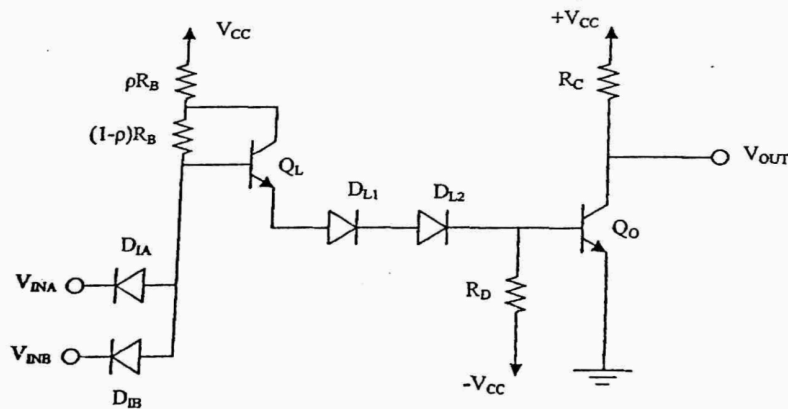


Question 3: [8 Marks]

Consider the following DTL NAND gate. Assume  $V_{BE}(FA) = 0.7V$ ,  $V_{BE}(SAT) = 0.8V$ ,  $V_{CE}(SAT) = 0.2V$ ,  $V_D(ON) = 0.7V$ ,  $\beta_F = 50$ ,  $R_D = 6K\Omega$ ,  $R_B = R_C = 1K\Omega$ ,  $\rho = 0.3$ ,  $V_{CC} = 5V$ . Find the following,

- VTC (sketch)
- The input low value of current  $I_{IL}$ .
- The output low value of current  $I_{OL}$ .
- The maximum fan-out
- The average power dissipation



a) assume  $V_{1A} = V_{1B} = V_{in}$

Output high voltage  $\equiv V_{OH}$

For  $V_{in}$  is low  $D_1$  is FB

$Q_L$ ,  $D_{L1}$ ,  $D_{L2}$  &  $Q_0$  is off

$$V_{out} = V_{CC} = V_{OH} \Rightarrow V_{OH} = 5V$$

Input low voltage  $\equiv V_{IL}$

Increasing  $V_{in}$  until the point where  $Q_0$  just turns on when

$$V_{in} = -V_D(ON) + V_{BE}(FA) + V_{D_{L1}}(ON) + V_{D_{L2}} + V_{BE_{Q0}}(FA) = V_{IL}$$

$$V_{IL} = 2V_{BE}(FA) + V_D(ON) = 2.1V$$

$$V_{IL} = 2.1V$$

Output low voltage  $\equiv V_{OL}$

For  $V_{in}$  is high  $D_1$  is off

$Q_L$ ,  $D_{L1}$ ,  $D_{L2}$  &  $Q_0$  is on

increasing  $V_{in}$  further eventually drives  $Q_0$  into saturation

$$V_{out} = V_{CEQ(sat)} = V_{OL}$$

$$V_{OL} = 0.2V$$

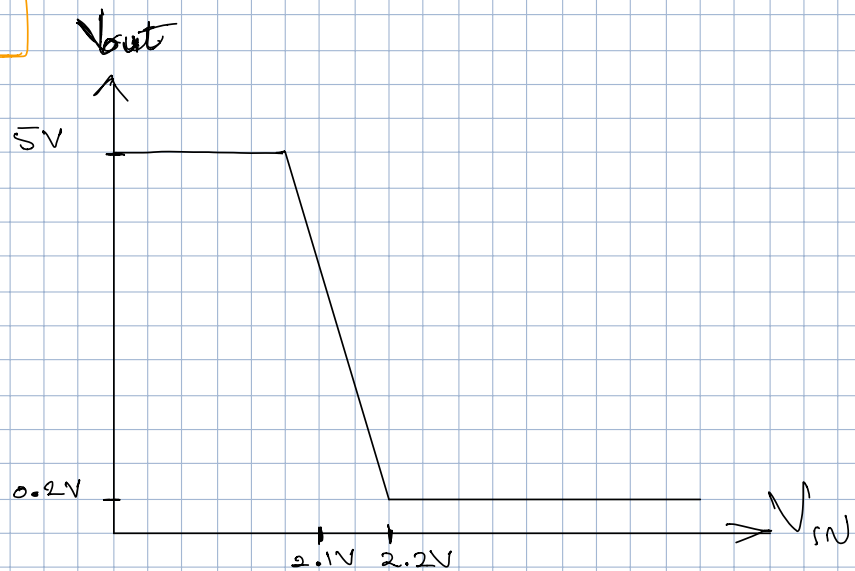
Input high voltage  $\equiv V_{IH}$

$Q_0$  enters saturation at

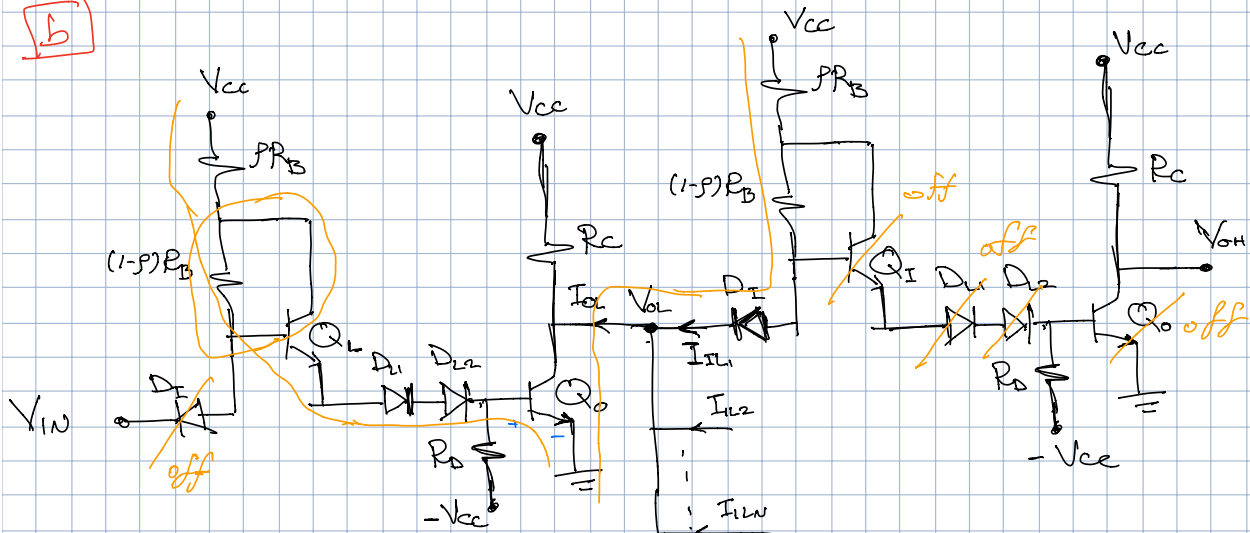
$$V_{in} = -V_{DI(ON)} + V_{BE_L(FA)} + V_{OL} + V_{OL} + V_{BE_Q(sat)} = V_{IH}$$

$$V_{IH} = V_{BE(FA)} + V_{BE(sat)} + V_{DI(ON)} = 0.7 + 0.8 + 0.7 = 2.2V$$

$$V_{IH} = 2.2V$$



(b)



Input low current  $\equiv I_{IL}$

$$I'_{IL} = I'_{R_B} = \frac{V_{CC} - V_{DI(ON)} - V_{CE,sat}}{(1-\beta)R_B + \beta R_E}$$

$$I_{IL} = \frac{V_{CC} - V_{DI(ON)} - V_{CE,sat}}{R_B} = \frac{5 - 0.7 - 0.2}{1K} = 4.1 \text{ mA}$$

$$I_{IL} = 4.1 \text{ mA}$$

[c] Output low current  $\equiv I_{OL}$

$$I_{OL} = I_{C,sat} - I_{RC}$$

$$I_{RC} = \frac{V_{CC} - V_{CE,sat}}{R_C} = \frac{5 - 0.2}{1K} = 4.8 \text{ mA}$$

$$I_{C,sat} = \beta I_{B,sat}$$

Assume  $\beta_{OL} = 1 \Rightarrow (EOC)$

$$I_{B,sat} = I_{E,L} - I_{RD} =$$

$$I_{RD} = \frac{V_{BE(sat)} + V_{CC}}{R_D} = \frac{0.8 + 5}{6K} = \frac{5.8}{6K} = 0.97 \text{ mA}$$

$$I_{E,L} = \frac{V_{CC} - V_{BE,L}(FA) - V_{OL1} - V_{OL2} - V_{CEP(sat)}}{\beta R_B}$$

$$= \frac{V_{CC} - V_{BE(FA)} - 2V_{D(ON)} - V_{BE(sat)}}{\beta R_B} = \frac{5 - 0.7 - 2(0.7) - 0.8}{(0.3)(1K)} = \frac{2.1}{0.3K}$$

$$I_{E,L} = 7 \text{ mA}$$

$$I_{B,sat} = 7 \text{ m} - 0.97 \text{ m} = 6.03 \text{ mA}$$

$$I_{C,sat} = 1 \times 50 \times 6.03 \text{ m} = 301.5 \text{ mA}$$

$$I_{O,L} = 301.5 \text{ m} - 4.8 \text{ m}$$

$$I_{O,L} = 296.7 \text{ mA}$$

[d]

$$N = \frac{I_{OL}}{I_{IL}} = \frac{296.7 \text{ m}}{4.1 \text{ m}} = 72.37$$

⇒ The maximum fan-out = 72

e

$$P_{cc}(\text{avg}) = \frac{I_{cc}(\text{OH}) + I_{cc}(\text{OL})}{2} V_{cc}$$

$$I_{cc}(\text{OH}) = I_{PR_B(\text{OH})} + I_{PC(\text{OH})}$$
$$= I_{PR_B(\text{OH})} = I_{IL} = 4.1 \text{ mA}$$

$$I_{cc}(\text{OH}) = 4.1 \text{ mA}$$

$$I_{cc}(\text{OL}) = I_{PR_B(\text{OL})} + I_{PC(\text{OL})}$$

$$I_{PR_B(\text{OL})} = I_{E,L} = \frac{V_{cc} - V_{BE_L(\text{FA})} - V_{OL1} - V_{OL2} - V_{BE_O(\text{sat})}}{R_B}$$
$$= 7 \text{ mA}$$

$$I_{PC(\text{OL})} = \frac{V_{cc} - V_{CE_O(\text{sat})}}{R_C} = 4.8 \text{ mA}$$

$$I_{cc}(\text{OL}) = 7 \text{ mA} + 4.8 \text{ mA} = 11.8 \text{ mA}$$

$$P_{cc}(\text{avg}) = \frac{11.8 \text{ mA} + 4.1 \text{ mA}}{2} (5) = \frac{15.9 \times 5 \text{ m}}{2}$$

$$P_{cc}(\text{avg}) = 39.75 \text{ mW}$$

extra

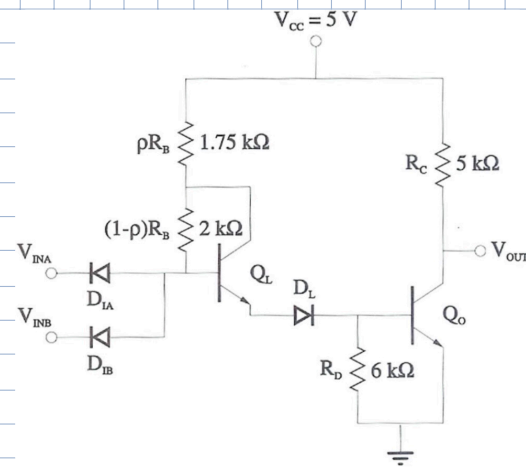
$$V_{NMH} = V_{OH} - V_{IH} = 5 - 2.2 = 2.8 \text{ V}$$

$$V_{NML} = V_{IL} - V_{OL} = 2.1 - 0.2 = 1.9 \text{ V}$$



6.16

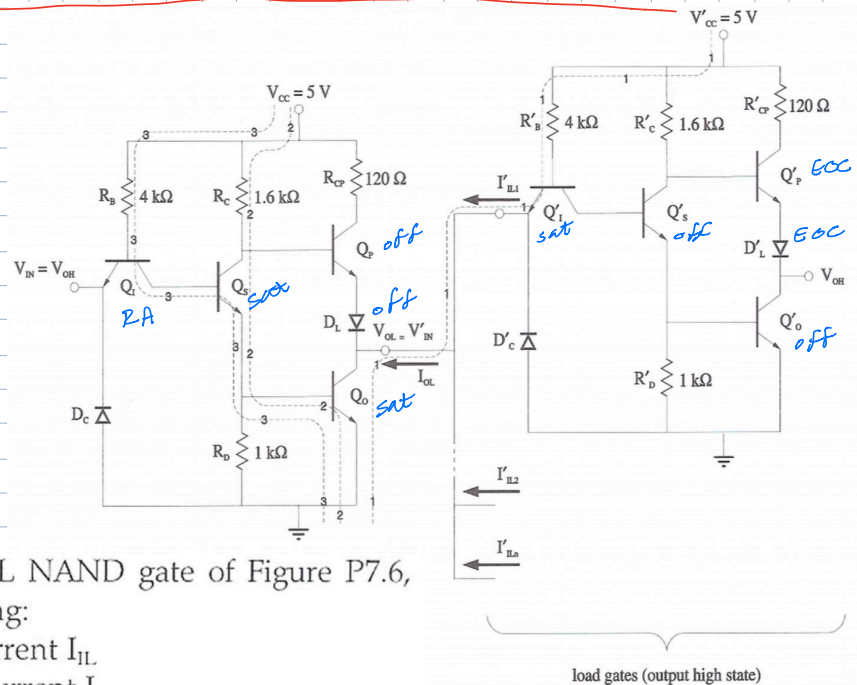
For the circuit of the right figure determine  $V_{OH}$  &  $V_{OL}$  for fan-out of  $N=10$



the fan-out  $N$  have  
no effect on  $V_{OH}$  &  $V_{OL}$  therefore

$$V_{OH} = V_{CC} = 5V$$

$$V_{OL} = V_{CE(sat)} = 0.2V$$



7.9 For the standard TTL NAND gate of Figure P7.6, calculate the following:

- the input low current  $I_{IL}$
- the output low current  $I_{OL}$
- the maximum fan-out  $\equiv N = I_{OL}/I_{IL}$
- the average power dissipation

Use  $\beta_F = 70$ ,  $\beta_R = 0.05$ ,  $V_{BE(FA)} = 0.7V$ ,  $V_{BE(SAT)} = 0.75V$ ,  $V_{BC(RA)} = 0.7V$ , and  $V_{CE(SAT)} = 0.15V$ . Use  $\sigma_O = 0.8$  for the output low state.

a 
$$I_{IL} = \frac{V_{CC} - V_{BE,I(sat)} - V_{CE,O(sat)}}{R_b} = \frac{5 - 0.75 - 0.15}{4k} = \frac{4.1}{4k}$$

$$I_{IL} = 1.025 \text{ mA}$$

$$b) I_{OL} = I_{C,O(sat)} = \alpha_F \beta_F I_{B,O(sat)}$$

$$I_{B,O(sat)} = I_{E,s} - I_{RD}$$

$$I_{RD} = \frac{V_{BE,O(sat)}}{R_D} = \frac{0.75}{1k} = 0.75 \text{ mA}$$

$$I_{E,s} = I_{C,s} + I_{B,s} = I_{RC} + I_{C,I(RA)}$$

$$I_{RC} = \frac{V_{CC} - V_{CE,s(sat)} - V_{BE,O(sat)}}{R_C} = \frac{5 - 0.15 - 0.75}{1.6k} = 2.56 \text{ mA}$$

$$\begin{aligned} I_{C,I(RA)} &= (1 + \beta_R) I_{B,I} = (1 + \beta_R) I_{RB} \\ &= (1 + 0.05) \frac{V_{CC} - V_{BE,I(RA)} - V_{BE,s(sat)} - V_{BE,O(sat)}}{R_B} \\ &= (1.05) \frac{5 - 0.7 - 2(0.75)}{4k} = 735 \mu\text{A} \end{aligned}$$

$$I_{E,s} = 2.56 \text{ mA} + 0.735 \text{ mA} = 3.295 \text{ mA}$$

$$I_{B,O(sat)} = (3.295 - 0.75) \text{ mA} = 2.545 \text{ mA}$$

$$I_{OL} = (0.8)(70)(2.545 \text{ mA}) = 142.52 \text{ mA}$$

c)

$$N = \frac{I_{OL}}{I_{IL}} = \frac{142.52 \text{ mA}}{1.025 \text{ mA}} = 139.04$$

The max fan-out is 139

d)

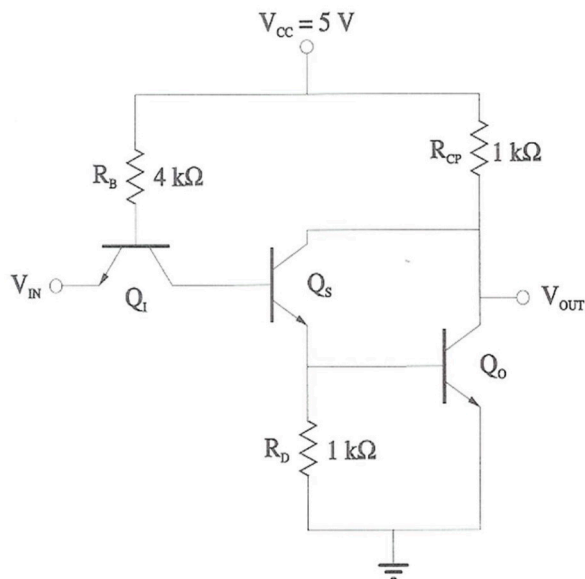
$$P_{CC(avg)} = \frac{I_{CC(OH)} + I_{CC(OL)}}{2} V_{CC}$$

$$I_{CC(OH)} = I_{IL} = I_{RB'(OH)} = 1.025 \text{ mA}$$

$$\begin{aligned} I_{CC(OL)} &= I_{RB(OL)} + I_{RC(OL)} \\ &= (0.7 + 2.56) \text{ mA} = 3.26 \text{ mA} \end{aligned}$$

$$P_{CC(avg)} = \frac{1.025 \text{ mA} + 3.26 \text{ mA}}{2} (5) = 10.71 \text{ mW}$$

- 7.12 For the "special" TTL inverter of Figure P7.12, let  $\beta_F = 100$ ,  $V_{BE}(FA) = 0.7$  V,  $V_{BE}(SAT) = 0.8$  V, and  $V_{CE}(SAT) = 0.1$  V. Obtain the following:  
 (a) Sketch the VTC.  
 (b) Determine the average power dissipation.



a)  $V_{OH}$ : For  $V_{in}$  is low

$Q_I$  is sat,  $Q_S$  &  $Q_O$  is off

$$V_{OH} = V_{CC} = 5V$$

$V_{OL}$ : For  $V_{in}$  is high

$Q_I$  is RA

Assume  $Q_S$  is FA &  $Q_O$  is off

find  $V_{CE,s} = ?$

when  $Q_O$  is off

$$V_{CE,s} = V_{CC} - I_{C,s} R_{CP} - I_{E,s} R_D$$

$$I_{E,s} \approx \beta_F I_{B,s}$$

$$I_{B,s} = I_{C,I} = (1 + \beta_R) I_{B,I}$$

$$\text{Assume } \beta_R = 0.05$$

$$V_{CC} - I_{B,I} R_B - V_{BE}(RA) - V_{BE}(FA) - I_{E,s} R_D = 0$$

$$V_{CC} - I_{B,I} R_B - V_{BE}(RA) - V_{BE}(FA) - \beta_F (1 + \beta_R) I_{B,I} R_D = 0$$

$$I_{B,I} = \frac{V_{CC} - V_{BE}(RA) - V_{BE}(FA)}{R_B + \beta_F (1 + \beta_R) R_D} = \frac{5 - 0.75 - 0.7}{4k + 100(1.05)1k} = 3.26 \times 10^{-5} \text{ mA}$$

$$I_{E,s} = \beta_F (1 + \beta_R) I_{B,I} = 100(1.05)(3.26 \times 10^{-5}) = 3.42 \text{ mA}$$

$$I_{C,s} \approx I_{E,s}$$

$$V_{CE,s} = V_{CC} - I_{C,s} R_{CP} - I_{E,s} R_D = 5 - 2k \times 3.42 \text{ m} = -1.84 \text{ V} \approx 0.1$$

$\Rightarrow Q_S$  (sat) &  $Q_O$  (FA) because  $\beta_{C,O}$  is RB

$Q_I$  (RA),  $Q_S$  (sat) &  $Q_O$  (FA)

$$V_{out} = V_{CE,s}(sat) + V_{BE,o}(FA) = V_{OL}$$

$$V_{OL} = 0.7 + 0.1 = 0.8 \text{ V}$$

$V_{IL}$ :  $Q_I$  (sat),  $Q_S$  (EOC),  $Q_O$  (off)

$$V_{IL} = V_{BE,s}(FA) - V_{CE,I}(sat) = 0.7 - 0.1$$

$$V_{IL} = 0.6V$$

$$V_{IB}: Q_I(sat), Q_S(FA), Q_O(EOC)$$

$$V_{IB} = V_{BE,s}(FA) + V_{BE,o}(EOC) - V_{CE,I}(sat) = 2(0.7) - 0.1$$

$$V_{IB} = 1.3V$$

$$V_{OB}:$$

$$V_{OB} = V_{CC} - I_{RP} R_{EP}$$

$$I_{RP} = I_{C,s} = I_{RD} = \frac{V_{BE,o}(EOC)}{1K} = 0.7mA$$

$$V_{OB} = 5 - 0.7mA \times 1K = 4.3V$$

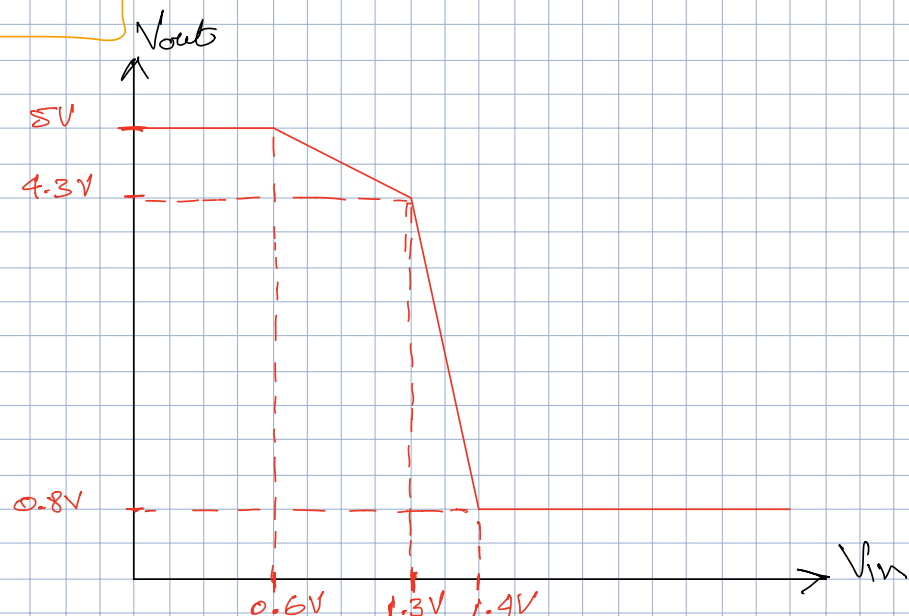
$$V_{OB} = 4.3V$$

$$V_{IH}: @ EOS \Rightarrow Q_I(FA), Q_S(sat) \& Q_O(FA)$$

$$V_{IH} = V_{BE,s}(sat) + V_{BE,o}(FA) - V_{CE,I}(sat)$$

$$= 0.8 + 0.7 - 0.1 = 1.4V$$

$$V_{IH} = 1.4V$$



Question 2: [7 Marks]

Consider the following TTL inverter. Assume  $V_{BE}(FA) = V_{BC}(RA) = 0.7V$ ,  $V_{BE}(SAT) = 0.8V$ ,  $V_{CE}(SAT) = 0.2V$ ,  $V_D(ON) = 0.7V$ ,  $\beta_F = 90$ ,  $\beta_R = 0.05$ ,  $\sigma_D = 0.8$  for the output low state,  $R_B = 40K\Omega$ ,  $R_C = 20K\Omega$ ,  $R_D = 12K\Omega$ ,  $R_{CP} = 500\Omega$ ,  $V_{CC} = 8V$ . Do the following:

- Sketch the VTC.
- Calculate the maximum fan-out.
- Calculate the average power dissipation.

a)

$V_{OH}$ :

For  $V_{in}$  low

$Q_E$  is sat,  $Q_S$  &  $Q_O$  off

$Q_P$  &  $D_P$  at EOC

$$V_{OH} = V_{CC} - V_{BE}(FA) - V_{D_P}(ON) \\ = 8 - 0.7 - 0.7 = 6.6V$$

$V_{IL}$ :

$V_{in}$  increased until  $Q_S$  becomes FA

$$V_{IL} = V_{BE}(FA) - V_{CE}(SAT) = 0.7 - 0.2 = 0.5V$$

$V_{IB}$ :

$V_{in}$  increases until  $Q_O$  becomes FA

$$V_{IB} = V_{BE,O}(FA) - V_{BE,S}(FA) - V_{CE,I}(SAT) \\ = 2V_{BE}(FA) - V_{CE}(SAT) = 2(0.7) - 0.2 = 1.2V$$

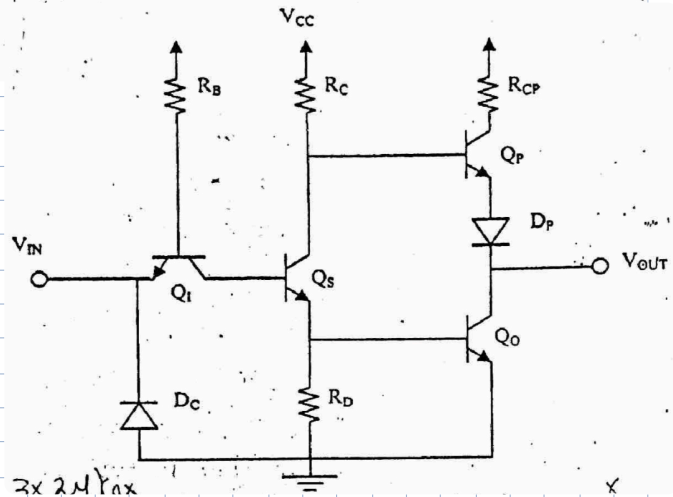
$V_{OB}$

As  $Q_O$  just turns on

$$I_{RC} = I_{RD} = \frac{V_{BE}(FA)}{R_D}$$

$$V_{OB} = V_{CC} - I_{RC}R_C - V_{BE}(FA) - V_{D(ON)} \\ = V_{CC} - \frac{V_{BE}(FA)R_C}{R_D} - V_{BE}(FA) - V_{D(ON)} \\ = 8 - \left(1 + \frac{20K}{12K}\right)(0.7) - 0.7 = 5.43V$$

$V_{IH}$ :  $V_{in}$  increases until  $Q_O$  &  $Q_S$  becomes saturated



$$V_{IH} = V_{BE,0(sat)} + V_{BE,s(sat)} - V_{CE,I(sat)}$$

$$= 2V_{BE(sat)} - V_{CE(sat)} = 2(0.8) - 0.2$$

$$V_{IH} = 1.4V$$

$V_{OL}$

$Q_0$  is saturation

$$V_{OL} = V_{CE(sat)} = 0.2V$$

$Q_P$  is therefore cutoff



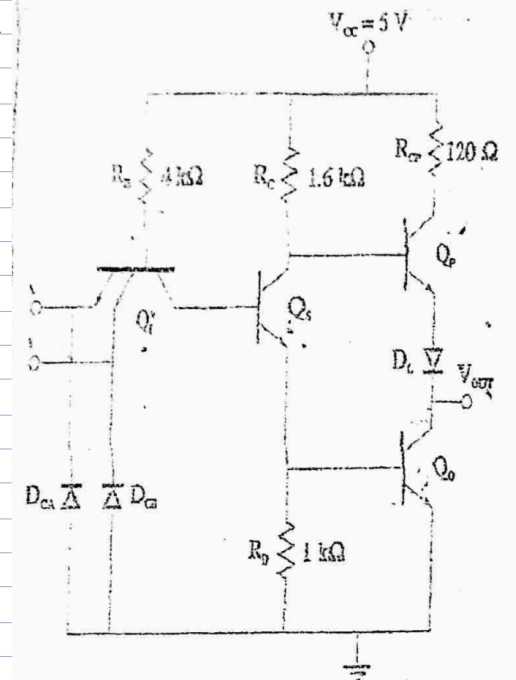
Element	$V_{OH}$	$V_{OB}$	$V_{OL}$
$Q_I$	sat	sat	RA
$Q_S$	cutoff	FA	sat
$Q_P$	EOC	FA	cutoff
$P_P$	EOC	EOC	cutoff
$Q_0$	cutoff	EOC	sat

Explain the operation of the totem-pole output buffer.

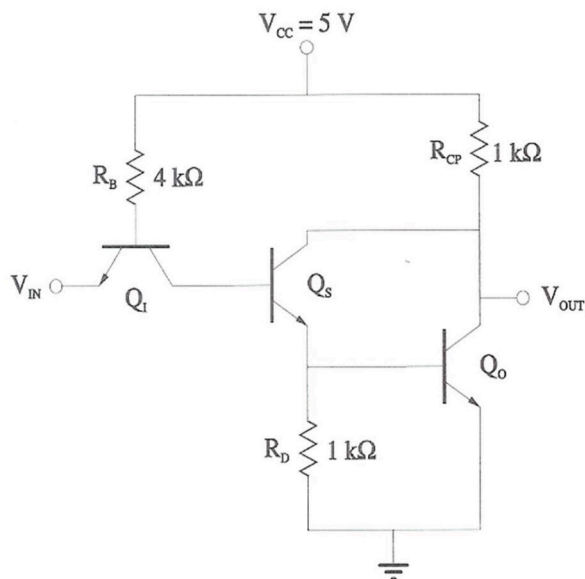
\*  $R_{cp}$  &  $Q_p$  provides active pull-up. thus a large current is available for charging the equivalent load capacitance when the output switches from low to high

$Q_o$  Output inverting BJT, output low driver for current sourcing pull-down  
 $D_L$  Diode level shifting between  $V_{CC}$  and output

\*  $Q_p$  &  $Q_o$  are never on simultaneously



- 7.12 For the "special" TTL inverter of Figure P7.12, let  $\beta_F = 100$ ,  $V_{BE}(FA) = 0.7$  V,  $V_{BE}(SAT) = 0.8$  V, and  $V_{CE}(SAT) = 0.1$  V. Obtain the following:
- Sketch the VTC.
  - Determine the average power dissipation.



$V_{OH}$ :

For  $V_{in}$  is low

$Q_s$  &  $Q_o$  is off

$$V_{OH} = V_{CC} = 5V$$

$V_{IL}$ :

As  $V_{in}$  increases  $Q_s$  enters EOC at

$$V_{IN} = V_{BE,s}(FA) - V_{CE,I}(sat) = V_{IL} \\ = 0.7 - 0.1 = 0.6V$$

$$V_{IL} = 0.6V$$

$V_{IB}$ :

As  $V_{in}$  increases further  $Q_s(FA)$  &  $Q_o$  enters EOC

$$V_{IB} = V_{BE,p}(FA) + V_{BE,s}(FA) - V_{CE,I}(sat)$$

$$V_{IB} = 2(0.7) - 0.1 = 1.3V$$

$V_{OB}$ :

As  $Q_o$  just turns on

$$V_{OB} = V_{CC} - I_{RCP} R_{CP}$$

$$I_{RCP} = I_{C,s} \approx I_{RQ} = \frac{V_{BE}(FA)}{R_D} = \frac{0.7}{1k} = 0.7mA$$

$$V_{OB} = 5 - 0.7mA \times 1k = 5 - 0.7$$

$$V_{OB} = 4.3V$$

$V_{IH}$ :

As  $V_{in}$  increases further  $Q_s$  just enter saturation

$$V_{IH} = V_{BE,s}(sat) + V_{BE,o}(FA) - V_{CE,I}(sat)$$

$$= 0.8 + 0.7 - 0.1 =$$

$$V_{IH} = 1.4V$$

$V_{OL}$ :

$Q_I$  enters RA &  $Q_s(sat)$  &  $Q_o(FA)$

$$V_{OL} = V_{CE,s}(sat) + V_{BE,o}(sat) = 0.1 + 0.7$$

$$V_{OL} = 0.8V$$

